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Overload-Resistant Pressure Sensors in the Nominal Range of 10 mbar (1 kPa)

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Abstract

Differential pressure sensors with silicon diaphragms provide a nominal measuring range of 10 mbar (1 kPa) at a measurement uncertainty of $\leq 2{\cdot}10^{-3}$. An additional external overload protection mechanism is required to achieve an overload reserve up to 160 bar (16 MPa). To integrate the overload protection at the wafer level, a micromechanical overload protection is needed. Such a micromechanical overload protection for differential pressure sensors can be produced from heat-treated glass. The functional principle limits the diaphragm deflection. Here, we demonstrate an overload capability reaching 50 bar (5 MPa) for a silicon diaphragm with a nominal measuring range of 10 mbar and a diaphragm thickness of 30 µm.

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Keywords: Differential pressure; Overload-Resistant; Defelction limiter

1. Overload-Resistant pressure sensors

Silicon differential pressure sensors provide good mechanical properties, due to their low hysteresis and zero point stability. Because of their basic overload capability $p < 1$ bar (100 kPa), an overload protection is required that does not affect the sensor's sensitivity. An integrated micromechanical overload protection reduces the complexity, compared to state-of-the-art external overload protection made of stainless steel with defined oil filling.

1.1. Homogenous deflection limiter made of glass

To prove the concept of homogenous deflection limiters made of glass, a first approach, with one-sided overload protection, has been realized. The important parameters of the production process are time, temperature and wafer thickness (Table 1). Prior to thermal treatment, the three-layer wafer stack, consisting of two silicon wafers and one glass wafer, must be positioned. The first laser-cut silicon wafer provides a substrate with defined openings (Fig. 1 a). A glass wafer is positioned on this substrate wafer. The placement of the pressure sensor dice is defined by custom openings in the second silicon wafer.

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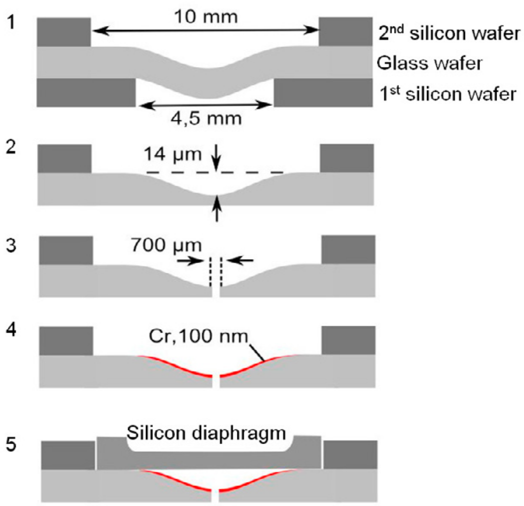
Table 1. Representative process parameters for deflection limiters with a depth of 14 µm.

	Test 1	Test 2
Wafer thickness silicon	420 µm	420 µm
Wafer thickness Borofloat 33	500 µm	800 µm
Holding temperature	750°C	750°C
Holding time	3 h	5 h

Clean room conditions are required to avoid the entrapment of particles. Placing the wafer stack horizontally in a chamber heated up to 750°C produces a softening of the glass (Fig. 1 a). Because of its own weight, the glass sinks slightly into the laser cut pattern in the silicon substrate wafer [1].

Further processing requires the removal the first silicon wafer, by lapping or grinding (see numbers 1-5 in Fig. 1 a). Using ultrasonic drilling, a capillary tube with diameter smaller than 700 µm is processed into the glass wafer, to ensure pressure equilibrium. Vacuum metalizing of a 100 nm thin chrome layer is needed to realize selective anodic bonding. Prior to the overload test, a silicon diaphragm is fixated by anodic bonding. Simultaneous processing of 21 pieces is possible. Ultrasonic drilling separates the deflection limiters including the silicon diaphragms into round samples with a diameter of 20 mm. An important property is the automatically flattened surface whose surface roughness is suitable for anodic bonding.

Bonding the silicon wafer and the glass wafer at 750°C causes a significant wafer bow. This wafer bow is avoided by using a second silicon wafer on top of the glass wafer. This makes the stack symmetrical (Fig. 1 b).



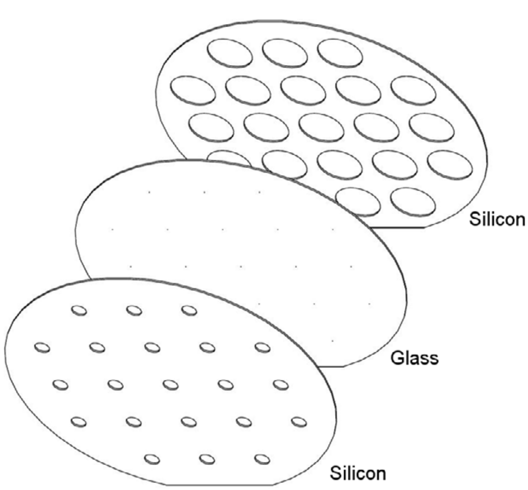


Fig. 1: (a) Process steps for wafer level setup; (b) Wafer stack prior to positioning under clean room conditions.

1.2. Overload test of silicon diaphragm with deflection limiter

We have produced deflection limiters whose average depth of the aspheric structure is 14 µm (Fig. 2 a). The separated samples are mounted into a test-housing. The pressure p is raised in discrete steps. A volume flow can be detected if the diaphragm is damaged (Fig. 2 b).

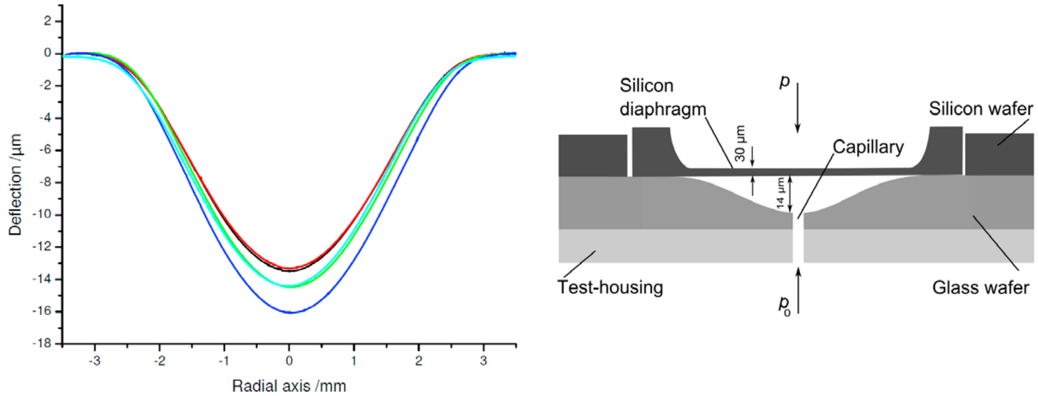


Fig. 2: (a) Measured representative curves of 6 glass deflection limiters; (b) Overload test of one-sided overload protected silicon chip with a deflection limiter made of glass.

A static overload pressure, lower than 50 bar (5 MPa) was applied successfully (Fig. 3 a). The influence of the static overload capability originated in the ultrasonically processed capillary, has to be determined in further designs. The first approach, with ultrasonically processed capillary tubes, achieves an overload capability of 50 bar (5 MPa) (Fig. 3 b).

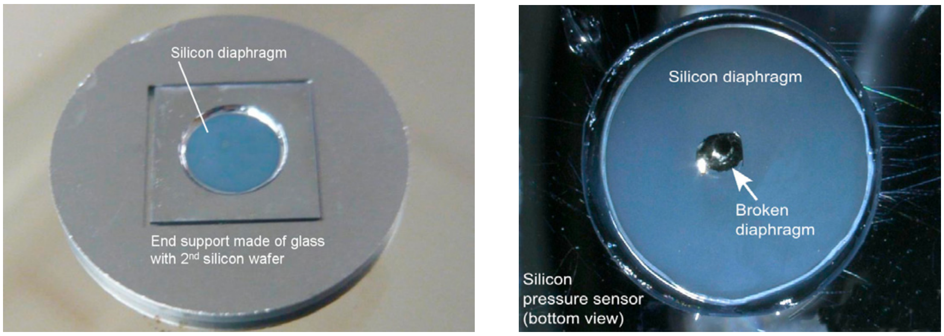


Fig. 3: (a) Overload test setup with deflection limiter made of glass; (b) Overload test with static pressure exceeding 50 bar (5 MPa).

1.3. Simulation of mechanical deflection and stress

In the absence of discontinuities, caused by processing the capillary tube, the overload capability is estimated to be Δp > 120 bar (12 MPa). The defection of a virtual diaphragm is simulated on a real deflection limiter with depth of 24 µm (Fig. 4 a). The simulation shows a free diaphragm movement for the nominal pressure range of 10 mbar. For differential pressure > 200 mbar, the silicon diaphragm adapts the deflection limiters aspheric shape.

If the overload pressure increases, the deflection is still limited to 24 µm and the structured deflection limiter provides an adapted, aspheric shape which prevents the diaphragm destruction. As a consequence of the limited deflection, the mechanical stress is also limited (Fig. 4 b). The mechanical stress at overload pressure is lower than 100 MPa, which preserves a reliable mechanical function.

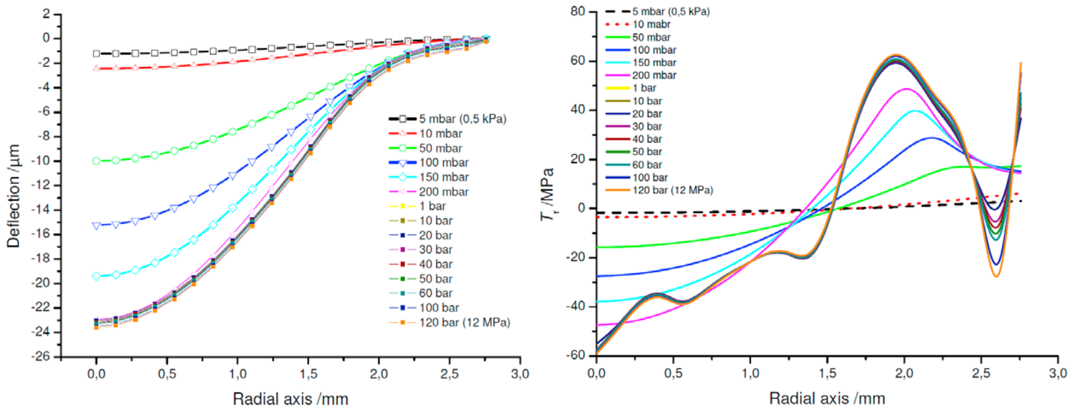


Fig. 4: (a) FEM simulation of diaphragm deflection over radial axis with a real deflection limiter; (b) FEM simulation of diaphragm stress T_r over radial axis with a real deflection limiter.

1.4. Further sensor concept

This concept will be further developed to a symmetrical layout with double-sided overload protection. Depending on the capillary diameter, the dynamic overload capability corresponds to the frequency response of the silicon diaphragm and the acoustic system. This correlation will be investigated with dynamic pressure calibration [2].

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